**Feedback and Climate Change**

Objectives: Students will be able to identify positive and negative feedback and describe how these impact global climate change.

Systems often exhibit two types of feedback; positive and negative.

**Positive feedback**: a change in the system causes further change in the system such that change becomes greater and greater.

**Negative feedback:** a change in a system causes an opposite response in the system such that the system remains in its original state.

Daisyworld

James Lovelock and Andrew Watson made of computer simulation of Daisyworld in 1983 to provide a model for how our own world may work. You can see an animation and brief explanation of Daisyworld at <http://library.thinkquest.org/C003763/flash/gaia1.htm>.

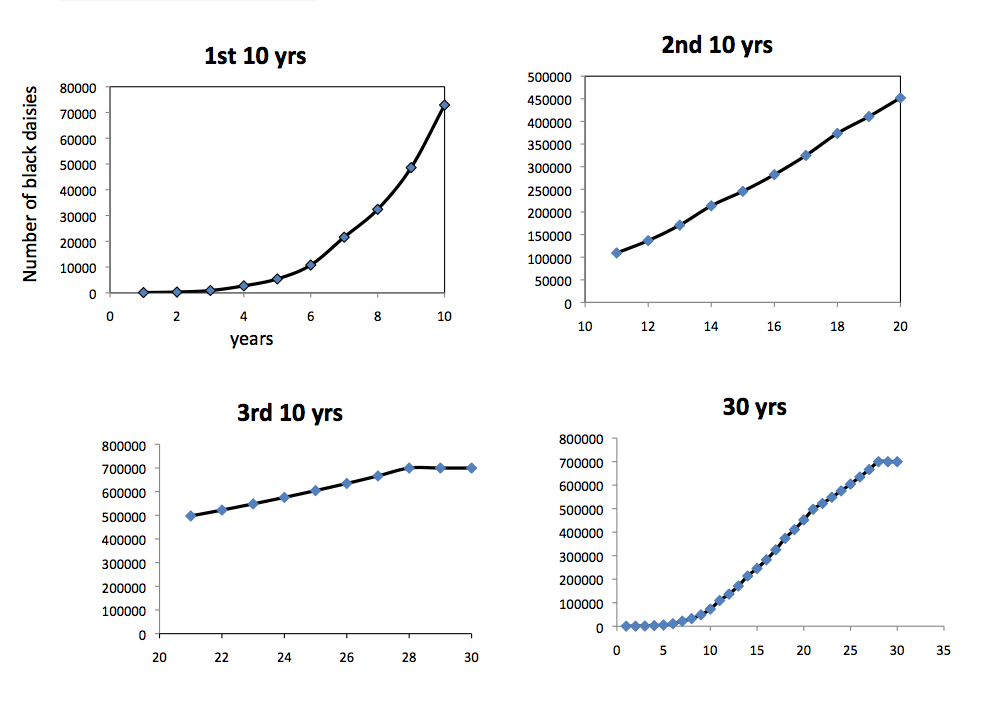
Daisyworld has only two inhabitants, black daisies and white daisies. Like all organisms, black and white daisies compete for space. Black daisies are better adapted to cold climates than white daisies because the black daisies absorb more sunlight. As they absorb sunlight, Daisyworld gets warmer. The warmer world is not optimal for black daisies because they overheat. White daisies are better adapted to hot climates because they reflect more sunlight than black daisies. As a result, the white daisies are less likely to over heat. Because white daisies reflect sunlight, the world gets cooler as the proportion of white daisies increases. A cooler world is not good for white daisies because they reflect sunlight and therefore do not gain much heat from solar radiation.

Daisies reproduce from seeds. Each plant, black or white, produces about 100 seeds. Of these, only about 3 germinate in optimal conditions creating new plants.

We’ll begin thinking about Daisyworld after a period of extreme cold. All the daisies are dead but previous generations of plants have left seeds scattered around the planet. Daisyworld is beginning to warm and plants begin to germinate. Because Daisyworld is cold, most of the successful plants are black daisies, so for now, let’s just consider what happens to them.

The first year, 100 black Daisies sprout and grow. Each of these daisies drops 100 seeds of which 3 germinate and sprout. Therefore, the second year, there are 300 daisies. Again, each of the 300 daisies drops seeds and give rise to 3 new plants. Therefore, the third year there are 900 daisies. In five years, there will be 8100 black daisies and in ten years there will be about 9 million. It seems that soon black daisies will cover the planet.

But the planet will not be overrun with black daisies because the more black daisies there are, warmer the planet becomes. With a warmer climate, the number of seeds which germinate declines. In fact, when daisy world is covered with about 9000 black daisies, the temperature is warm enough that each plant still generates 100 seeds but only 2 of these germinate. After awhile, only 1.5 per 100 seed generate, then 1.0 per hundred as the climate gets still warmer. Figure 1 shows four graphs of the number of black daisies per year. During the first ten years the number of black daisies increases rapidly. The rapid increase causes Daisyworld to warm so the number of new plants begins to drop. During the second ten years, the lower rate of regeneration results in a continued but slower rate of increase in the number of black daisies. Still, with increasing numbers of black Daisies, Daisy world continues to warm. During the final 10 years, the number of black daisies increases then finally levels off so there is no longer an increase in the number of black daisies and therefore the temperature of Daisyworld remains constant. The lower right graph in figure 1 shows the change in the number of black daisies over a thirty-year period.



Daisy world would not be very interesting if there were only one kind of daisy. After awhile, daisy world would evolve to have a fixed number of black daisies and a fixed temperature. But Daisyworld is interesting because there are also white daisies. As the world gets warmer, the white daisies begin to regenerate faster and faster because heat doesn’t bother them the way it does black daisies. So white daisies begin to spread faster and faster. As they do this they crowd out the black daisies. At the same time, unlike the black daisies, which made the world warmer, white daisies reflect sunlight and make the world cooler. Eventually, the world gets cold enough that white daisies begin to die off. As they die off, there is more room for black daisies.

Daisy world continues to fluctuate back and forth between cooler climates that favor the black daisies and warmer climates that favor the white daisies (figure 2). Does that sound d a bit like the earth’s climate?

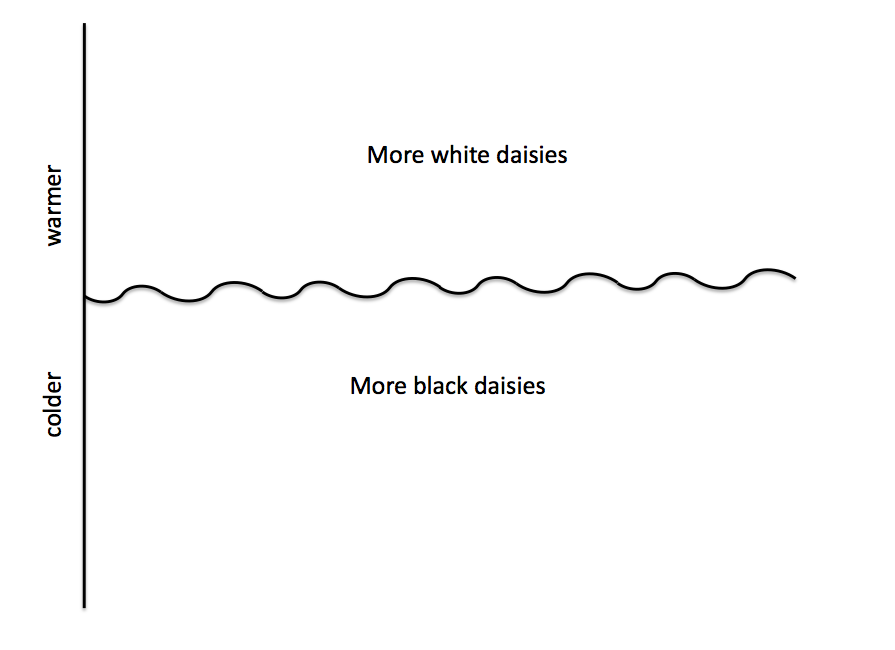


Figure 2. In Daisyworld the number of black and white daisies and temperature fluctuate due to feedbacks in the system

Lovelock and Watson developed Daisyworld because they thought it might provide insights into the dynamic earth system that has, of course, many more variables than Daisyworld, which affect the climate. Daisyworld is a very simple model of how a biological system might respond. When considering the earth’s climate, we need to consider biological and non-biological parts of the system. Water is one non-biological component of the climate system that involves both positive and negative feedback loops.

Consider what may happen to the earth as the average temperature increases. When temperature rises evaporation rates increase. With increased evaporation, the water vapor content of the atmosphere will increase. This happens because warm air can hold more water vapor than cold air (Figure 3). If you will recall, water vapor is a greenhouse gas so with increased water vapor in the atmosphere, the greenhouse effect will become stronger and the planet will undergo even more warming. This further warming will cause yet more evaporation, adding more water vapor to the atmosphere causing even more warming.

Figure 3.

If this were all that were happening on earth, our planet would get warmer and warmer. But other factors play a role. As the amount of water vapor in the atmosphere increases, so must the amount of clouds and clouds reflect incoming solar radiation, resulting in a cooling of the earth and a decrease in the rate of evaporation.

There are many other examples of changes in the Earth system that may amplify warming or cooling trends. For example, when the climate gets colder, glaciers expand. As glaciers cover more land surface, the amount of sunlight reflected from the earth’s surface expands because glaciers reflect more sunlight than the land surface. The increase in reflection leads to further cooling and yet more glaciers. The opposite happens during periods of warming. As the planet warms, glaciers melt and this results in less reflection of sunlight. With less solar radiation the planet gets still warmer.

***Part A. Alignment and Inference Generation.***

Lovelock and Watson designed Daisyworld to be analogous to Earth. That is, there are features of the Daisyworld that correspond with features of Earth. They correspond because they each are systems that exhibit positive and negative feedback. Before aligning Daisyworld with the Earth describe features and relationships mechanisms of each the Daisyworld (Table 1) and the Earth (Table 2) in correspondence how those features and relationships impact the climate system. For example, black daisies are a feature of daisy world. The one important relationship is that warm the climate by absorbing solar radiation. This is not the only important relationship involving black daisies. Therefore, the same feature (e.g. black daisies) is listed twice so you can state more than one role. Features are also listed twice in the Earth table (table 2)

Table 1

|  |  |
| --- | --- |
| **Daisyworld features** | **Relationships** |
| Black daisies | Warm the climate |
| Black daisies | *Regenerate most successfully in cold climates* |
| Seed generation | *Generations of both grow faster than they die at optimal conditions* |
| White daisies | *Cool the climate* |
| White daisies | *Regenerate most successfully in warm climates* |
| Seed generation | *Generations of both grow faster than they die at optimal conditions* |

Table 2

|  |  |
| --- | --- |
| **Earth features** | **Relationships** |
| evaporation | *Adds water to atmosphere* |
| Water vapor in atmosphere | *Increases with increase temperature* |
| Water vapor in atmosphere | *Heats the atmosphere* |
| Clouds | *Reflect solar radiation, cooling the atmosphere* |
| glaciers | *Grow in cooler climates and shrink in warmer climates* |
| glaciers | *Reflect solar radiation causing climate to cool* |

Now we will align features and relationships of Daisyworld and Earth by listing features in table 3 from both that play similar roles in the climate. For each set of features, state if it is part of a positive or negative feedback. Note that for some features, the feedbacks may not be the same. For example, both white daisies and glaciers reflect solar radiation. On Daisyworld, the reflection of solar radiation is part of a negative feedback system whereas glaciers reflecting solar radiation are part of a positive feedback system on earth.

Table3

|  |  |  |
| --- | --- | --- |
| **Earth feature** | **Daisy world feature** | **Role in climate** |
| glaciers | White daisy | Reflect solar radiation. Negative feedback white daisies positive feedback for earth |
| clouds | *White daisy* | *Reflect solar radiation. Negative feedback for Daisyworld, negative feedback for Earth* |
| Water vapor | *daisies drops 100 seeds of which 3 germinate and sprout* | Both cause positive feedback. |
| Glacier-free surface | *Black daisies* | Absorb radiation. Negative feedback for black daisies, positive feedback for earth |

***Part B. Important Differences between Earth and Daisyworld***.

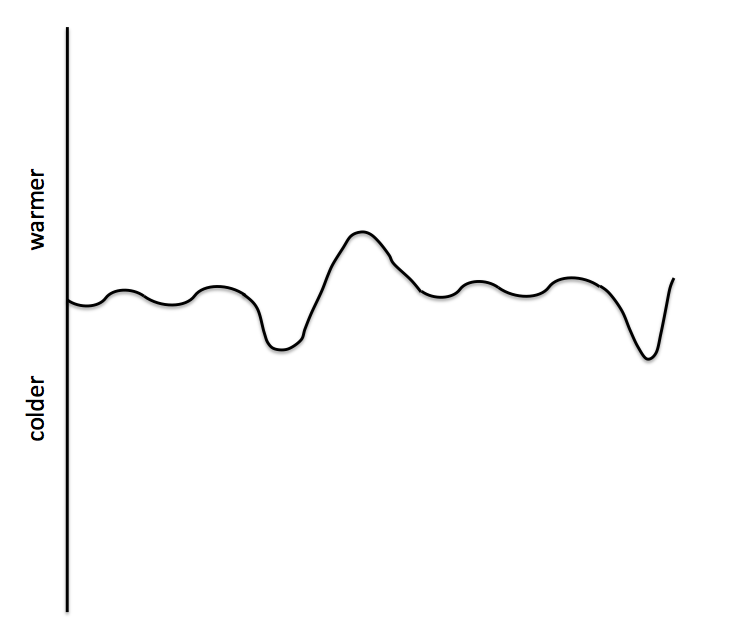
Making Analogies isn’t just about finding what’s similar between two domains, but also discovering and understanding important differences.

When aligning the Daisyworld and Earth, it is clear that the earth system has multiple feedbacks whereas the becomes Daisyworld has only daisies.

1. Figure 3 has a similar shape to the upper left graph in figure 1. What if anything does this imply about the processes that these graphs represent?

*Nothing*

2. How might a system with multiple feedbacks differ from a system with only daisies? Figure 2 shows temperature variations in Daisyworld. Draw a similar diagram for a world with multiple feedbacks. Explain why it looks the same or different from figure 2.



*The curve will be more irregular as the system switches between dominate feedbacks.*

Assessment:

Carbon dioxide is an important greenhouse gas and a necessary component for life. During photosynthesis, plants combine water and carbon dioxide into sugars and from these sugars, they construct the complex organic molecules. Some plants have been shown to grow faster in warmer, CO2 rich environments than they do in colder, CO2 poor environments. If this relationship proves to be true of most plants, how will this effect global warming?

*This would be a negative feedback and tend to stabilize climate.*